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# SEQUENTIAL LEARNING AND GESTURE PRODUCTION IN CHILDREN WITH SPECIFIC LANGUAGE IMPAIRMENT

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# ABSTRACT

Implicit learning is defined as learning without awareness. Previous studies have tested children with specific language impairment (SLI)'s ability to exhibit implicit learning in a Serial Reaction Time (SRT) Task. Stemming from the idea that children with SLI often have problems with motor skills in addition to language, our study consisted of an SRT task containing four different gestures as the stimuli. Our task was given to college-aged adults and children both with and without language impairment. It was anticipated that normally developing participants' gesture production would vary from the random sections to the sequential portions of the task. If implicit learning was exhibited, participants performed the sequential portion quicker than the random portions. In addition, the study examined the errors the children produced while participating in the task, examining if the motor aspect was an explanation for slower performance and reaction times. The adults who participated in our study exhibited the components of sequential learning, validating the usability of our task. When administering the task to the children, sequential learning was shown in two out of the five children. There are multiple variables to look at when considering the reason why we found mixed results and not all children exhibited sequential learning. This pilot data can be used in order to alter the task for future research that looks at larger a population of children who have a diagnosis of SLI.

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# ACKNOWLEDGEMENTS

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# INTRODUCTION

## Specific Language Impairment

Specific Language Impairment (SLI), also known as developmental language disorder or developmental aphasia is considered a diagnosis of exclusion, for the language impairment exists without any other obvious mental or physical handicap, hearing loss, emotional disorder, or environmental deprivation (Hill, 2001). Although expression and severity of the language impairment may vary from child to child, common characteristics of SLI include delay in first words, simplified grammatical structures, and overall difficulty with both receptive and expressive language. When tested, language abilities are found to be significantly below what is expected based on a child’s age and IQ. Children with SLI score in the lowest 10% on standardized assessments that focus on receptive and expressive language (Bishop, 2006).

According to the MIT Encyclopedia on Communication Disorders (Kent, 2003), children with SLI have difficulties that span most, if not all, areas of language. Not all domains are affected in the same way or to the same extent, as both strengths and weaknesses exist. Vocabulary and pragmatics are often relative strengths and phonology and morphosyntax are relative weaknesses. Morphosyntax often seems to be the most affected area in children, as noted previously in the difficulties experienced with grammatical structures (Kent, 2003). Certain causes for specific language impairment like poor parenting and transient hearing loss have been ruled out years ago, leaving researchers to question and wonder about the etiology of this disorder. A possible gene for SLI is being investigated, while there is also a focus on underlying deficits in cognition. Approximately 7% of five-year-olds have SLI and it occurs more often in males than females (Kent, 2003). Due to the prevalence, further study is imperative.

**Procedural Learning**

Ullman and Pierpont (2005) proposed the Procedural Deficit Hypothesis (PDH), which attributed SLI to a deficit in the brain and more specifically, procedural learning. They claimed that difficulties in procedural learning could explain problems that children who have SLI experience with grammatical structures, for the same brain structures are involved in both. Procedural learning includes performing tasks that have sequences present in them, like riding a bicycle or typing. Acquiring theses skills is a gradual process that initially requires trial and error, but once the skills are learned, the procedure occurs much more quickly. The brain structures involved in the process encompass not only motor tasks similar to those mentioned, but also specific functions of language like grammar, lexical retrieval, dynamic mental imagery, working memory, and rapid temporal processing. The Procedural Deficit Hypothesis states that many individuals with SLI have brain abnormalities in the procedural system, which can result in lexical retrieval deficits and issues with the rules of grammar. Ullman and Pierpont have evidence to support their hypothesis in the form of structural, metabolic, and functional neuroimaging, in addition to postmortem brain examination. The results of these anatomical studies provide strong evidence for the hypothesis that individuals with SLI also have brain abnormalities in at least two structures of the brain: the frontal cortex and the basal ganglia (Ullman & Pierpont, 2005).

Despite the evidence Ullman and Pierpont presented to support their hypothesis, they did not conduct any tasks to directly test the procedural learning deficit. Intrigued by the Procedural Deficit Hypothesis, Tomblin, Mainela-Arnold, and Zhang (2007) decided to examine it further by directly testing participants. In their experiment, the researchers used a Serial Reaction Time (SRT) task. When a creature appeared on the computer screen in a certain place, the study participant was asked to push a corresponding button (out of four possible options). Four phases of the sequence occurred – beginning and ending with random patterns of 100 presentations of the stimuli, with a set of 200 that followed a specific, repeating pattern in between. It is assumed that human response time will decrease during production of a familiar pattern due to an implicit learning of the pattern. As response time decreases, speed increases during production of a familiar pattern. Implicit learning allows the participant to anticipate the upcoming stimulus item, allowing for increased speed. Response time then increases and speed decreases during production of a random sequence since the brain has not implicitly recognized a pattern. The experimenters did, in fact, find a difference in SRT between children with SLI and their normally developing peers. Unlike the normal language group, the children with SLI showed a stable or even slowed response during the pattern phase. These results indicated that difference in language abilities between adolescents with SLI and normal language peers could be explained by deficits in procedural learning (Tomblin et al., 2007).

## Motor Skills

Although a difference in language abilities and procedural learning ability definitely exists, it has also been proposed that SLI is not a disorder of just language, for difficulties in other domains are also present. In 2001, Elizabeth Hill published a paper reviewing all literature on SLI that discussed concomitant motor impairments. In order to examine both fine and gross motor skills, she reviewed studies that used tasks like “timed peg moving, finger opposition, and bead threading as well as line walking, hopping, and tasks of balance” with the children (Hill, 2001, p. 155) . The review concluded that there is significant co-morbidity between SLI and motor deficits, not existing as a sub-group, but in the majority of the children who have SLI (Hill, 2001).

Marton (2009) agreed that children with SLI exhibit impairments in gross motor skills but also acknowledged that not many studies had been conducted to test it. She stated that due to the interaction between motor and perceptual skills, one would expect a child with poor gross motor skills to also struggle with imitation tasks. Her study examined imitation of body postures and hand movements through activities like bilateral motor coordination and imitation of postures tasks. Children with SLI did show a weakness in imitation of body postures and hand movements, performing more poorly than their age-matched peers in all tasks assessing it. In addition, children with SLI had a lessened sense of their body in space and performed poorly on gross motor tasks, exhibiting more complex errors than typically developing children. The findings of this study suggest that weakness in imitation skills in early childhood may indicate possible language problems later on. Because motor skills were a strong predictor of imitation, examination of these skills early on can help to identify those who are at risk for language impairment; thus, intervening early to target language (Marton, 2009).

Stemming from the idea that impairments in motor skills may be an indicator for language difficulties, Vukovic, Vukovic, and Stojanovik (2010) studied the connection further. With two groups of children, 30 with SLI and 30 typically developing, their study compared both motor and language abilities. It also examined the relationship between the abilities and whether motor abilities predict language skills. Each child was tested individually on language abilities, in multiple areas such as story generation and articulation. They were also tested on motor skills through coordination of legs and arms, as well as imitation of movements. As we would expect, children with SLI performed lower than typically developing children in the area of language abilities – producing ungrammatical clauses and misarticulating sounds. However, a new finding of this study was that the children with SLI performed significantly lower than the typically developing children in almost all language tasks and all motor tasks. A developmental trajectory showed that these children were delayed in the development of the motor skills. In addition, some language abilities seemed to be associated with different motor abilities. For example, articulation abilities in children with SLI were correlated with leg and arm coordination. This study does not claim to prove an underlying cause of SLI, but it draws some new conclusions that may help in assessment of co-occurring deficits (Vukovic, Vukovic, & Stojanovik, 2010).

**Gesture Production**

A more specific type of motor skill lies in the category of gestures. A study by Hill and her colleagues (1998) set out to compare qualitative aspects of motor performance in children with SLI and those with developmental coordination disorder (DCD) by examining children's abilities on praxis tests. According to Hill, praxis tests focus on how well an individual can "produce purposeful skilled movements and involves the motor programming and motor integration required to execute complex and learned movements" (Hill, 2001, p. 159). The researchers evaluated the children on their performance of transitive and intransitive representational gestures, in response to both a verbal command and imitation. In addition to comparing the children with DCD and SLI to a chronological age –matched control group, the experimenters also included a control group made up of younger children. The addition of this younger group examined whether a possible explanation for the difficulties of the children with SLI and DCD is the immaturity of a developing system (Hill, 1998).

Seventy-two children in total were assessed in the areas of language skills, motor competence, and gesture production. After analysis with a detailed error system, it was shown that the children with DCD, SLI, and the younger controls performed similarly to one another, but different than the age-matched control group, making more errors across the board. Although the children with SLI performed significantly lower than their normally developing peers, it is important to note that they produced similar errors, just at a higher rate (Hill, 1998).

The fact that the children with DCD and SLI showed similar performance brings up the question of whether the deficits are the consequence of anatomical structures being close in the brain or if they are both signs of brain development immaturity. The fact that the children with SLI (even more so than those with DCD, who in one aspect, performed more poorly) performed more similarly to the younger control group than the age-matched control group provides support for the brain immaturity over the brain damage theory (Hill, 1998).

**Connecting gesture production and motor skills**

A combination of the two kinds of studies previously mentioned in this paper, a paper by Iverson and Braddock (2011) examined gesture *and* motor skill in relation to language in children with language impairment (LI). They first acknowledged the co-occurrence of language impairment and motor deficits that Hill described. In addition, the researchers hypothesized that gestures might be used to compensate in times of expressive difficulty. They referenced other studies that examined this through Piagetian conservation tasks, as well as retelling from memory, finding that when attempting to solve the task, children with LI used gestures twice as much as their TD peers did when working on the task. Their gestures were also found to be more iconic than those of their peers, suggesting that gesture, independently, may act as a predictor of language ability. Similarly to many of the studies already previously described in this paper, Iverson and Braddock noted that other work has looked at the relationships between language and gesture and between language and motor abilities separately in children with LI. They questioned whether gesture or motor skill could independently predict a child's language ability. They also wondered whether the relationship between gesture and motor skill is similar to the typically developing peers of children with LI (Iverson & Braddock, 2011).

Since most of the work also examining the relationships described focused on school-age children, the researchers on this study decided to target preschoolers. The study included 11 preschool aged children with LI and 16 children with typical development (TD). Since the Piagetian and retelling tasks were not developmentally appropriate for these young children to examine gesture use, narrative tasks were utilized instead. The children were shown a cartoon and picture book, and asked to tell a 10-

minute story about what was depicted. The gestures were analyzed and each placed into one of the following four categories: Deictic, Conventional, Representational, or Beat gestures. In addition to classifying the gestures, the researchers calculated the frequency of gesture production and examined how they connected to language. Following the communication tasks, the researchers examined motor skills through two different methods. The first method used a developmental task where the researchers observed a child's ability to perform 11 fine motor tasks and 9 gross motor tasks. They also took into consideration a form of parental report that questions a child's ability on 30 different fine and 30 different gross motor tasks. Finally, the children's cognition and language were considered using tests that looked at auditory comprehension and expressive communication, which also focused on nonverbal abilities.

It was found that the children with language impairment spoke fewer words per minute and used gestures almost one and a half times more than the typically developing group. Although the majority of communication used consisted of language for both groups, the LI group had more attempted utterances that solely relied on gesture. In the area of motor skills, the children in the LI group performed significantly more poorly than their TD peers in all categories assessed. Through an in-depth analysis, the researchers discovered that in only the LI group, poorer expressive language was linked to more frequent production of gestures. However the group also concluded that "despite the co-occurrence of language and motor difficulties among the children with LI, there was no indication that this influenced their production of gestures either quantitatively or qualitatively." (Iverson & Braddock, 2011, p. 82)

**Research Questions**

The current study set out to combine many of the aspects of SLI discussed. Children with and without language impairment were tested on a Serial Reaction Time task that contained gestures. Both sequential learning and motor skills were examined. The children were asked to imitate the gestures as quickly as possible. Similar to the expectation of Tomblin et al. (2007), unlike in a typically developing child, it was hypothesized that a child with language impairment would not complete the sequential pattern phase of the task more quickly than the random portions at the beginning and end. This could be due to a deficit in sequential learning.

Also, even though Iverson and Braddock (2011) hypothesized motor deficits may not explain struggles in a gesture production task, this relationship was examined in the current task. In addition to being asked to imitate the gestures as quickly as possible, the children were asked to form the hand shapes as accurately as they appeared on the screen that they could. As Hill and her colleagues (1998) concluded in their gesture production task, children with language impairment did not produce errors different from their normal language peers, but the same errors more frequently.

It is hypothesized that all children will exhibit errors such as imprecise production and inaccurate production, where they may produce one of the other four gestures. However, where as normal language children will have these error types infrequently throughout the task, the number of these errors will be higher for the children with language impairment. In analyzing the production of the gestures, whether poor motor skills may contribute to difficulty forming the gestures; and in turn, in the performance of the overall task was examined. The pilot data collected in this experiment will then be useful in the execution of a similar task with children who have a diagnosis of SLI.

# METHODS

## Participants

In order to recruit participants, a partnership with the Language and Literacy Research Initiative (LLRI) housed within the Department of Communication Sciences and Disorders at Penn State University was established. This research initiative recruits preschool and school-aged children both with and without language and reading disorders. Researchers conduct a battery of tests on the children, results of which are then stored in a database for use in future projects on the development and disorders of spoken and written language. The child participants in the current study consisted of five children, one male and four females. The participants ranged in age from 7 to 12 years old. Five college-age adults (three males and two females) were also recruited through the use of flyers and word of mouth. Both left-handed and right-handed children and adults were included in our hand-shape experiment.

## Stimuli

The stimuli for this study were presented in the form of a 200 slide PowerPoint presentation. There were two versions of the slideshow – one for right-handed participants and one for left-handed participants. We took photographs of each hand shape with a digital camera and printed the images. We then traced each image with a black marker and scanned the images back into the computer. The images consisted of four different hand shapes (pictured in Figure 1). They were a fist, a C-shape facing downward, a flat palm (with palm facing down), and a flat palm (with palm facing out). These images were each assigned a number and then arranged both randomly and sequentially in the 200 slide PowerPoint presentation. Using a web-based random number generator, we determined the random order of the presentation of the first 50 slides. The middle 100 slides were organized sequentially, repeating the 10-image pattern of 1-3-2-4-4-2-3-4-2-4. To conclude the presentation, the last 50 were in a different random sequence, determined also by the random number generator.

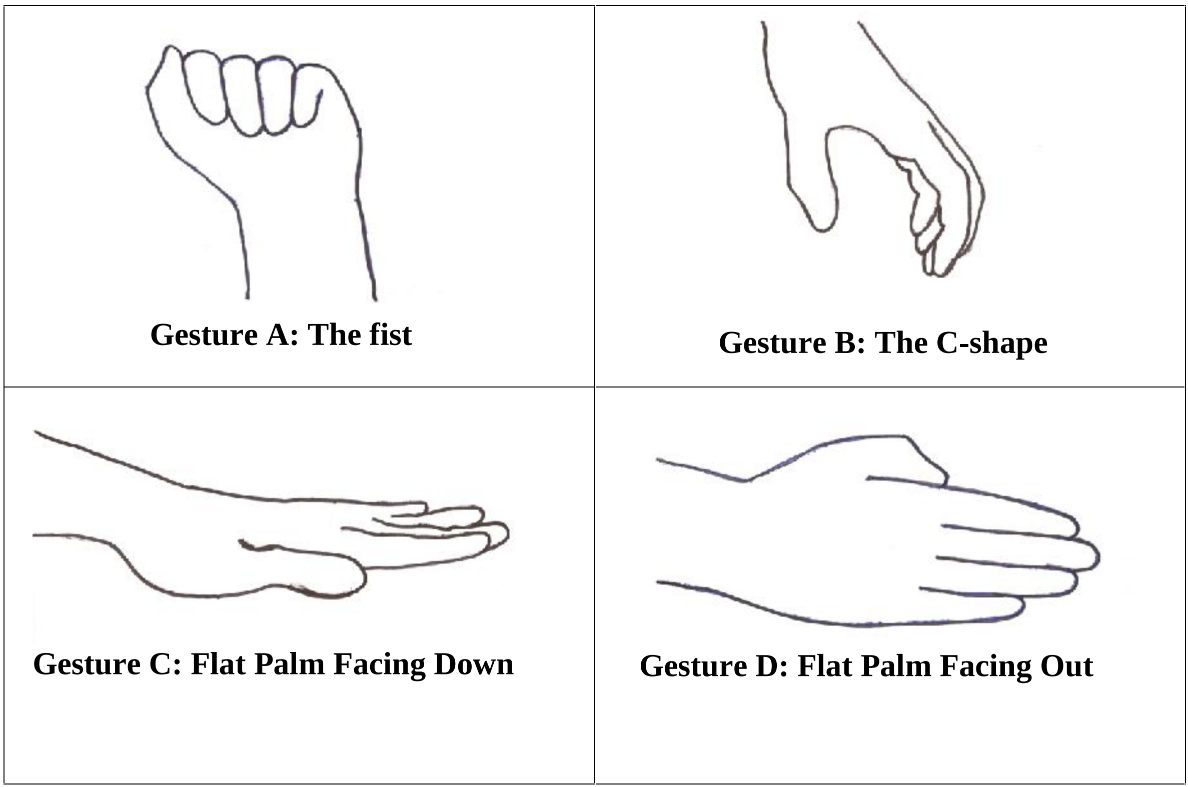


**Figure 1: Illustrating the Left-Handed Gestures**

## Procedure

Undergraduate researchers from LLRI were trained on how to administer the hand-shape task and it was incorporated it into the assessment sessions with the children. Depending on the handedness of the participant, the appropriate presentation was selected. The participant sat in a chair facing the computer with a researcher sitting beside him or her. Following each slide, the researcher would use the spacebar to advance to the next slide. A camera was stationed behind the participant's seat in order to capture the view of both the computer screen and the hand shape being produced by the child. Another researcher was standing behind the camera to make sure it was positioned correctly. The experiment was also conducted with the adult participants, following the same procedure described above. However, the hand-shape experiment was the only task the adults engaged in, as no language tests were given.

The participants were instructed on the computer screen as follows: "You are going to see different hand shapes. We want you to imitate them as quickly and accurately as possible. After imitating each shape, place your hand back on the desk." The participant was then shown a slide of each hand shape in order to familiarize him or her with each gesture. There were then nine random slides of the gestures so that the participant could practice producing the gestures in a sequence, in addition to putting the hand down in between. During these practice slides, the researchers checked the accuracy of the gesture production, making corrections if needed. In order to decrease fatigue, there were four break slides distributed in the actual presentation. In order to increase motivation, there was a pie chart showing progress on each break slide, in addition to phrases like "Keep up the good work" and "You're almost there."

**Analysis**

In order to analyze the adults' participation in the study, the tapes of their session were reviewed. First, the presentation was separated into four sections – the first 50 random, the first 50 sequential, second 50 sequential, and last 50 random. The time stamp on the video camera screen was used in order to measure the times for each section. Timing began with the first gesture production of the first slide in the first set of 50. Time was stopped once the final gesture in that set of 50 was completed. Time was started over for the next set of 50 and this pattern continued for the rest. Later, to analyze further, the 200 slides were divided into groups of 10 and timed. So for the sequential section, there were 10 repetitions of the pattern. The times were graphed, comparing the random to the sequential (see Figures 2-6). For the adult participants, a graph was created that showed the average times across all five participants (see Figure 7).

The same procedure was used in order to gather and graph the times of the child participants. However, in addition to the time each section took, the errors produced throughout the session were also examined. A list of error types was composed, using Hill's (1998) paper on representational gestures as a guide. Since the current study looked at a different type of gestures than Hill (1998), six errors that were relevant to our specific study were used from her list. The error-types focused on are described in Table 1. In order to gather this data, a checklist of the errors was used while watching the tapes of the child participants. Each child was given 200 trials, or opportunities, for gesture production. When watching the session, one trial was watched at a time – observing whether the production was correct or incorrect. In the event of an incorrect gesture production, which error occurred was noted from the list. Following this data collection step, the error-types and their frequencies were graphed.

**Table 1: Description of Gesture Errors**

| | |
|---|---|
| **Amorphous** | **Movement bears no resemblance to that requested** |
| **Clumsy** | Clumsy or awkward movement |
| **Delayed Imitation** | Correct movement is shown after a delay |
| **No response** | No response |
| **Preservation** | Participant repeats previous action |
| **Unsustained** | Movement starts accurately, quickly deteriorates |

*Note*. Adapted from "Representational Gestures in Developmental Coordination Disorder and specific language impairment: Error-types and the reliability of ratings," by E.L. Hill, D.V.M. Bishop, and I. Nimmo-Smith, 1998, *Human Movement Science, 17*, p. 665. Copyright 1998 by Elsevier Science B.V.

In order to examine relationships between language ability and performance on the gesture sequence task, language scores on various tests were included in our analysis. The Clinical Evaluation of Language Fundamentals—4 (CELF-4) was used for the school-aged participants and The Clinical Evaluation of Language Fundamentals-Preschool—2 (CELF-P2) was used for the younger participants. For the study, the following sub-tests of the CELF-4 were used: Following Directions, Recalling Sentences, Formulating Sentences, and Word Structure. During the Following Directions subtest, the child points to pictures following an oral cue. For Recalling Sentences, the student imitates sentences that the test examiner presents. The Formulating Sentences subtest asks children to create a sentence about a picture, using a target word or phrase. The Word Structure subtest asks children to complete sentences using the targeted structure. The average score on the subtests is 10, with a standard deviation of 3 for all children.

The data includes a Core Language Standard Score and Expressive Language Index for each child. The Core Language score is a total of multiple subtests that best discriminate between typical and atypical language performance (Semel, Wiig, and Secord, 2008). The Expressive Language Index is also a summation of subtest scores, focusing on those that test expressive skills. The overall average score for children is 100, with a standard deviation of 15.

# RESULTS

## Child Language and Cognition Scores

Table 2 presents the scores on the CELF-4, both the sub-tests and Core Language Standard Score and Expressive Language Index. There is also a note regarding cognition that varies with the participants. Each child was given either the WASI or the Leiter-R IQ test, depending on his or her age. It is also noted whether the child has an Individualized Education Program. Table 3 presents the data for the younger child participants who were tested with the CELF-P2.

**Table 2: Language Scores for school-age child participants in the gesture sequence task**

| CELF-4 subtest categories | AAA31 | BAA 76 | BAA 77 | BAA 81 | BAA 03 |
|---|---|---|---|---|---|
| Following Directions | 7 | 14 | 9 | 6 | 15 |
| Recalling Sentences | 8 | 13 | 8 | 9 | 10 |
| Formulating Sentences | 6 | 10 | 7 | 10 | 11 |
| Word Structure | N/A | 9 | 4 | 4 | 11 |
| Core Language Standard Score | 83 | 109 | 82 | 84 | 112 |
| ELI Expressive Language Index SS | 83 | 103 | 77 | 87 | N/A |
| Other Notes regarding cognition | WASI Perf IQ: 88 | WASI Perf IQ: 104 | WASI Perf IQ: 91 | Has an IEP | Leiter-R: 129 |

**Table 3: Language Scores for pre-school child participants in the gesture sequence task**

| CELF-P2 Sub-Tests | BAA01 | BAA03 |
|---|---|---|
| Expressive Vocab | 11 | 11 |
| Sentence Structure | 9 | 10 |
| Leiter-R IQ Score | 109 | 129 |

## Child Participants Data

Figures 2-6 present the data collected for the times it took our five child participants to complete the gesture sequence task. The times are broken down into the following groups of gesture stimuli: 1st 50 Random, 1st 50 Sequential, 2nd 50 Sequential, and Final 50 Sequential.

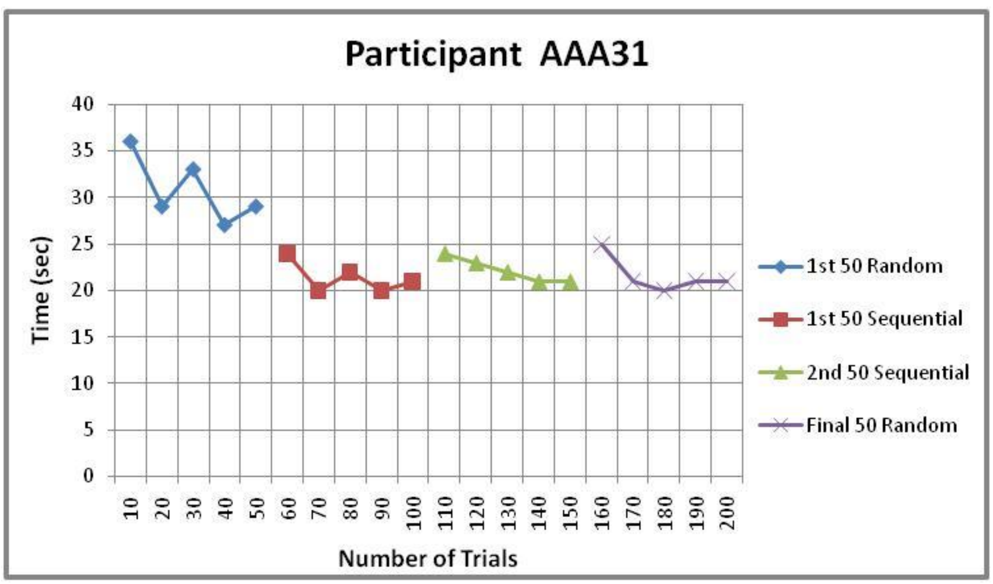


**Figure 2: Trends in Gesture Production Time for Child Participant AAA31**

Figure 2 indicates that implicit learning occurred when Participant AAA31 completed the gesture sequence task. There is a noticeable decrease in time immediately after the first random phase ends and the sequential phase begins. After the sequential phase is completed, there is an immediate increase in time for the first 10 trials of the final random phase. However, the last 40 of the random section are completed more quickly, showing times similar to those in the sequential phase.

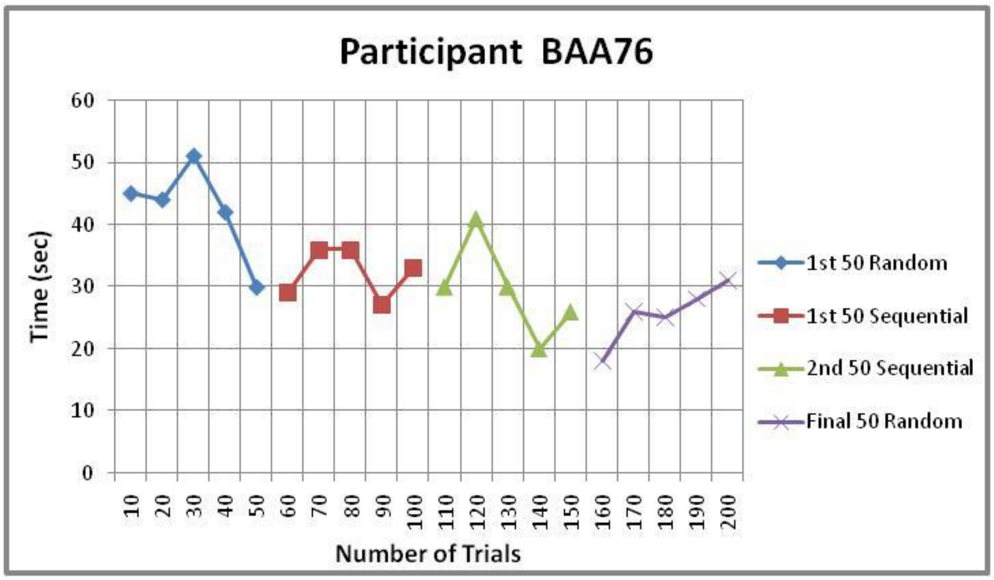


**Figure 3: Trends in Gesture Production Time for Child Participant BAA76**

Figure 3 indicates that sequential learning did occur in the case of Participant BAA76. There is a noticeable decrease in time overall in the sequential section when compared to the first random section. Although there is an unexpected decrease at the beginning of the last random section, the last 40 trials of the task steadily increased in time. The time is slower overall for the last 50 random gestures.

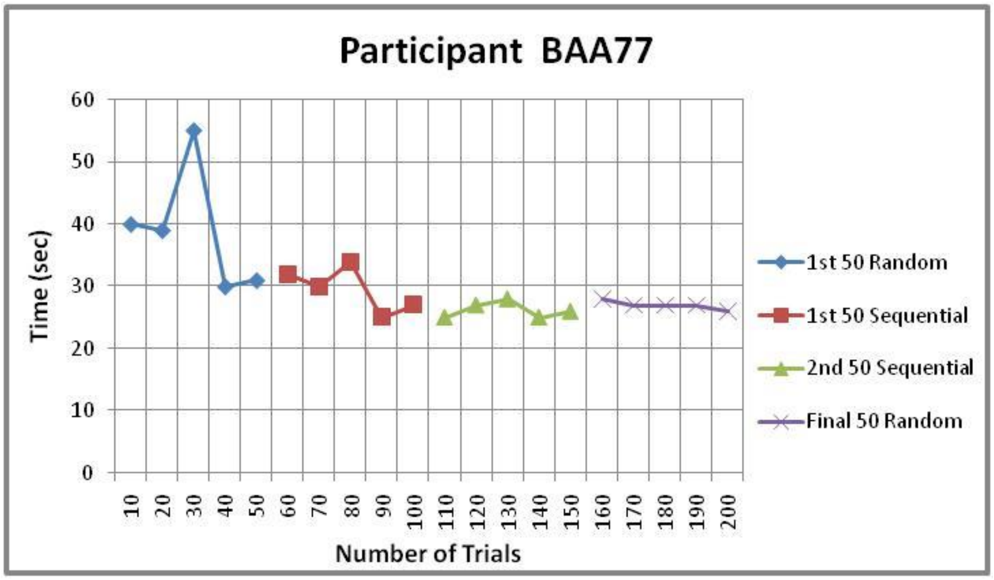


**Figure 4: Trends in Gesture Production Time for Child Participant BAA77**

As evident in Figure 4, BAA77 did not exhibit evidence for sequential learning. There is a decrease in time from the first random to the sequential, which is one piece of evidence necessary. However, the second set of sequential trials and the final random set of random trials are very similar in times, rather than showing an increase in time for the final random set which indicates sequential learning has occurred.

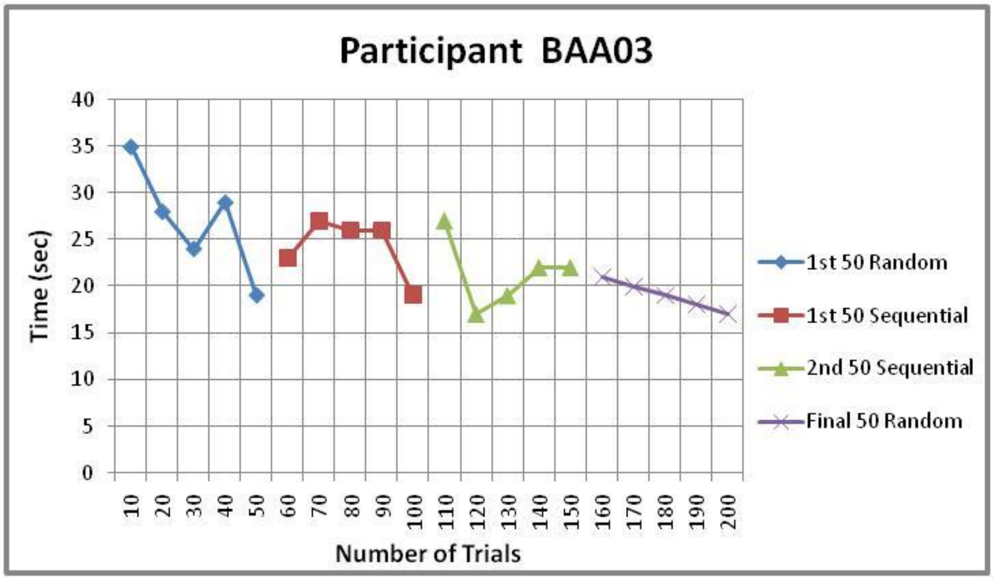


**Figure 5: Trends in Gesture Production Time for Child Participant BAA03**

Figure 5 does not show all components of sequential learning in the case of Participant BAA03. There is a decrease in time from the first 50 random to the sequential set, but the times are variable in the sequential section. Furthermore, instead of an increase in time at the final random set that is indicative of sequential learning, there is a steady decrease in time during that set. This participant got faster overall, rather than implicitly learning the pattern.

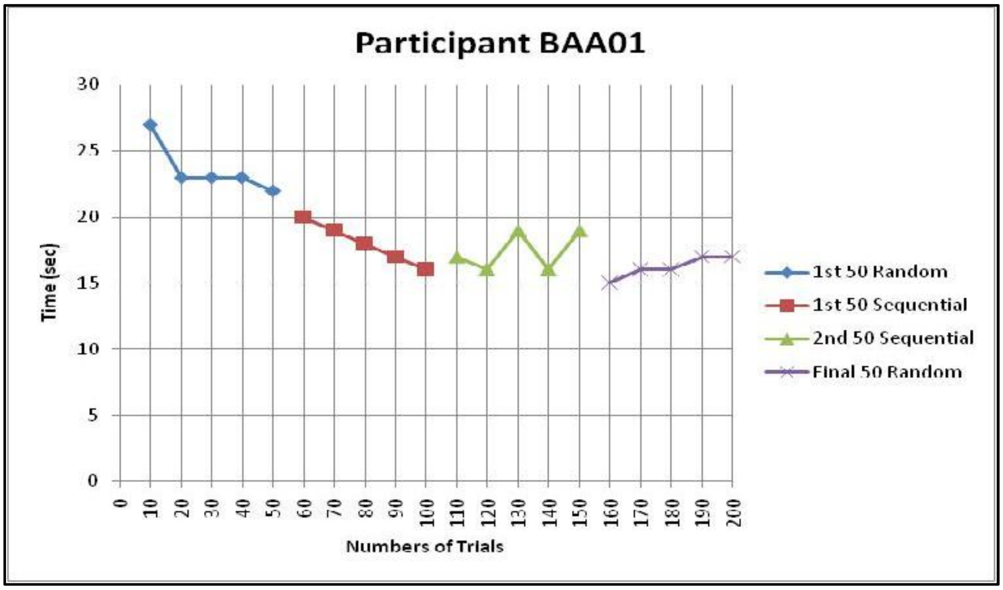


**Figure 6: Trends in Gesture Production Time for Child Participant BAA01**

As shown in Figure 6, Participant BAA01 does not show implicit learning. There is a decrease in time overall from the first random to the first sequential set, but the time begins to increase during the second sequential set where we would expect the time to decrease even more. In addition, the final random set does not show an increase in time, rather the participant completed it faster than the sequential set.

## Adult Participants Data

Figure 7 presents the average times of completion on the gesture sequence task across all five adult participants. When the times are averaged, there is a clear indication of implicit learning. There is an immediate decrease in time following the first random phase and the time continues to decrease during the sequential pattern. When the pattern is removed and the gestures return to a random sequence, there is an immediate increase in time.

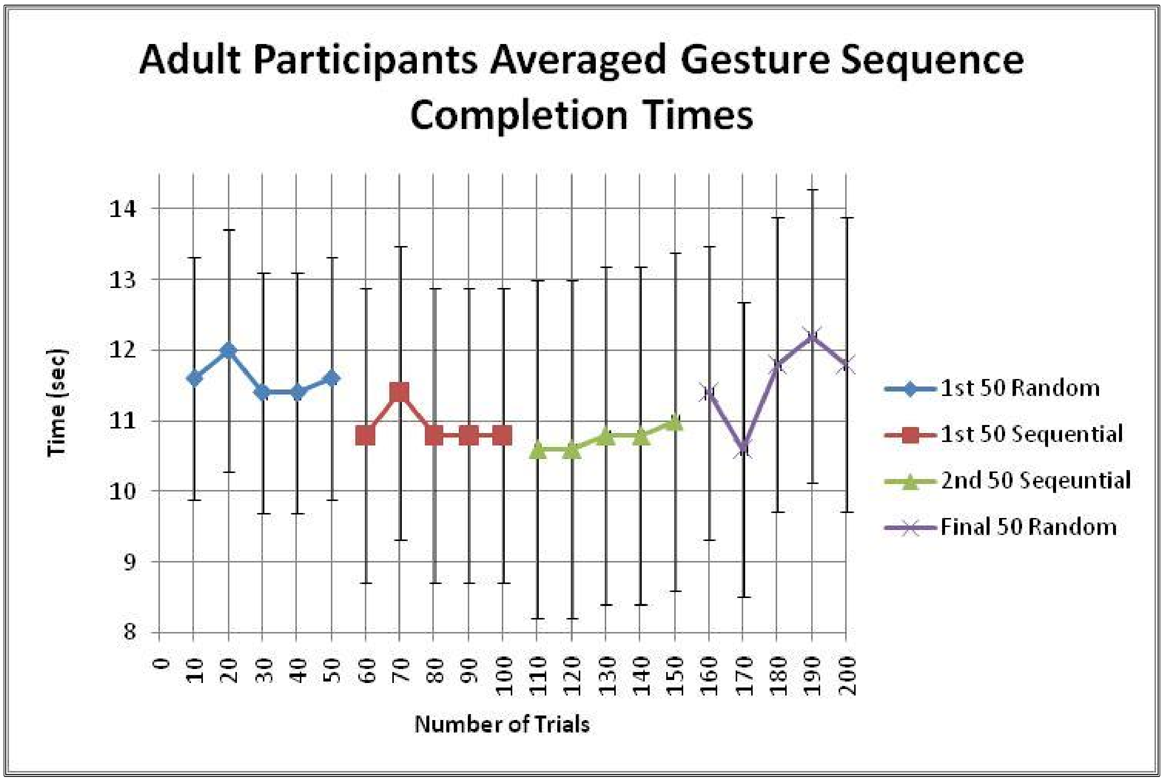


**Figure 7: The averages in time for the adults completing the gesture sequence task with error bars indicating standard deviations**

## Error Analysis of Children's Gestures

Figure 8 presents the total numbers of errors that were exhibited by six child participants. The five children with timing data from the gesture sequence task are presented, in addition to a sixth participant, BAA81. Participant BAA81's times on the task had to be discarded due to stalls in the administering of the task, but his tape was kept in order for his gesture errors to be analyzed.

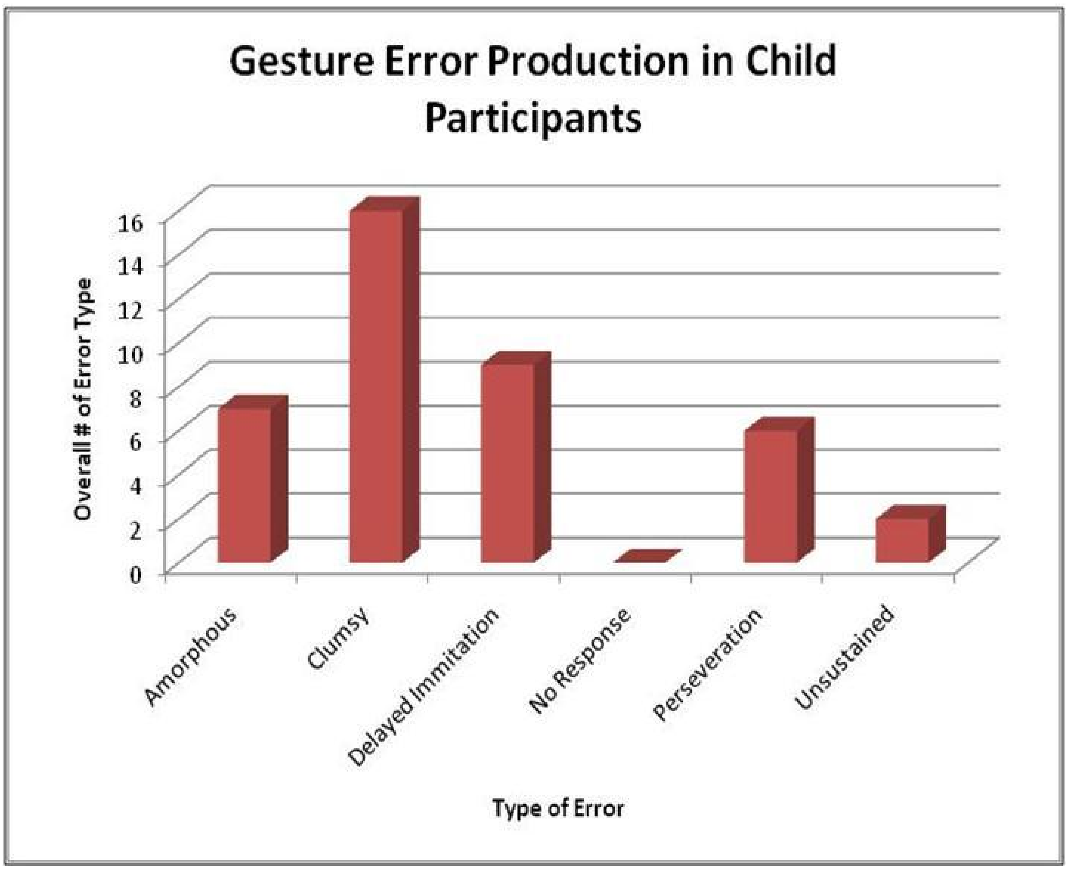


**Figure 8: Total number of each gesture type produced by child participants**

Table 4 breaks down the errors produced by each individual child. All six error types are listed and the table includes how many times the children produced each of the different gestural errors.

**Table 4: Number of each error types produced by child participants**

| | BAA81 | AAA31 | BAA76 | BAA77 | BAA03 | BAA01 |
|---|---|---|---|---|---|---|
| Amorphous | 5 | 0 | 1 | 0 | 1 | 0 |
| Clumsy | 4 | 0 | 3 | 3 | 5 | 1 |
| Delayed Imitation | 4 | 2 | 1 | 0 | 2 | 0 |
| No Response | 0 | 0 | 0 | 0 | 0 | 0 |
| Perseveration | 2 | 3 | 0 | 1 | 0 | 0 |
| Unsustained | 1 | 0 | 0 | 0 | 1 | 0 |
| Total Number of Errors | 16 | 5 | 5 | 4 | 9 | 1 |

# DISCUSSION

The current study set out to test children of varying language abilities with a Serial Reaction Time task that contained gestures. Using the work of Tomblin et al. (2007) as a guide, it was expected that where as a typically developing child would perform the sequential portions of the task quicker than the random portions, a child with a language impairment would not experience such trends; thus, not showing signs of sequential learning. In order to test the usability and reliability of our task, the experiment was also run on a set of adults to see if they would show implicit learning. In addition, the current study looked at errors in gesture production, asking whether, as was found in Hill's (1998) work, children with language impairment produced more errors due to problems with motor skills, which in turn affected their overall performance on the task. Although the children in the current task do not have a diagnosis of SLI, they have varying levels of language ability and similar performance was expected compared to those of researchers who have studied implicit learning and motor skills in children with SLI.

## Adult Gesture Completion Times

Despite some variability among individual performances, on average, implicit learning was evident in the adults' results on the gesture sequence tasks (see Figure 7). When simply comparing the sequential portions to the random portions of the test, there was approximately a 4-5 second difference between the two. This was readily apparent at both the beginning and ends of the test, indicating that participants were able to recognize the patterns in the sequential learning implicitly and execute the gestures more quickly.

While the decrease from the first set of random gestures to the first set of sequential gestures was expected, it was the increase in gesture production time after both sets of sequential data that confirmed implicit learning was occurring instead of just becoming more acclimated to the testing. Furthermore, there was a 2 second decrease in the production of the second set of sequential gestures compared to the first set. This showed that the participant was catching on to the 10-gesture pattern. This implicit learning made it easier for the participant to anticipate what stimuli would next appear. He or she was then able to produce the sequence with more efficiency. These differences indicate that, on average, an implicit learning of the gesture pattern occurred during the sequential learning task.

## Child Gesture Completion Times

Much more variability was apparent in the times that the child participants took to complete the gesture task, making it more appropriate to examine them on an individual basis, rather than on average. A case can be made that sequential learning occurred in child participants AAA31 and BAA76. Child Participant AAA31 (see Figure 2) exhibited a noticeable decrease in time from the first random portion of gestures to both the first and second set of sequential portions. In order to allow for sufficient exposure to the gesture sequence and for implicit learning to occur, it is especially telling to look at the time difference between the first random set and the second set of fifty sequential gestures. Participant AAA31 completed the sequential set approximately 43 seconds (or 27%) faster than the random set, indicating that the sequence had been implicitly learned. Although there was not a sharp increase in the time taken to complete the final random set as anticipated, we can tell from the graph shows that the data in the final random set is slower compared to the end of the sequential phase. In the case of Child Participant BAA76 (see Figure 3), there was also a noticeable decrease in the time taken to complete the sequential set. This participant completed the second sequential set approximately 66 seconds (or 26%) faster than the first set of random gestures. After completing the sequential portion, it is clear to see on the graph that the time steadily increased when the task returned to the random portion at the end. The fact that there was not an immediate increase in time at the beginning of the final random set can be explained by the brain taking time to adjust to the change in stimuli. Once the participant realized the pattern was no longer present after exposure to the first 10 random gestures, the time taken to complete increased. This data indicates that the participant implicitly learned the gesture pattern, completing the sequential section quicker, where as his production slowed when he was presented with random gestures and he did not recognize a pattern.

Although implicit learning may not have occurred in our other three participants, it is still important to look at their data and consider the factors that may have affected their performance. In the case of participant BAA77 (see Figure 4), there was a definite decrease in time from the first random set to the sequential set. However, there was not an increase in time for the final random set. The time taken to complete the second sequential set of gestures was very similar to the time taken to complete the final random set and the graph levels off. A different phenomenon occurs in the data of participant BAA03 (see Figure 5). Although there was a decrease in time from the first random to the sequential sets, there was also a decrease in time from the sequential sets to the final random set. This participant got faster overall, rather than just during the sequential portion of the task. The final child participant, BAA01 (see Figure 6) exhibited times that were similar to that of participant BAA03. There was a strong decrease in time from the first random portion to the first sequential set and then the times steadily decreased from there for the duration of the task.

## Variability in Gesture Errors and Language Scores

Due to the co-morbidity between SLI and motor deficits that Hill (2001) reviewed in her research and the problems that children with SLI have with imitation tasks according to Marton (2009), it was important to examine whether the motor aspect would have an effect on children's implicit learning in our task. In an empirical study, Hill (1998) stated that in a gesture production task, children with SLI produced errors similar to those of their normally developing peers, but at a higher rate. The children with SLI also produced errors that were similar to the younger control group of children who participated in the experiment. Adapting Hill's error list, six errors that could be shown during participation in this task were focused on (see Table 1). Due to her conclusions, it was anticipated that children with language impairments may have immature and imprecise gestures most frequently. This hypothesis was affirmed in the fact that the most common gestural error produced across all child participants was clumsiness (see Figure 8). All other gesture errors were present at least once except for no response as the children gave each gesture presented to them a try. In addition to these five participants, the gesture errors of BAA81 were also examined. Data from this participant had to be discarded because although he did finish the task, he stopped multiple times, often talking to those administering the task. The interruptions would not allow for sequential learning to occur. This participant struggled with the task, taking about twice as long as the other participants without counting his off-task moments.

Due to the fact that in past research, children with SLI have struggled with sequential learning tasks, language assessment scores were evaluated to determine whether a possible language impairment affected the performance of the child participants on the task. Participant BAA81 did not exhibit implicit learning on the task, but he also struggled overall with the completion of the task. When looking at this participant's language and cognition scores (see Table 2), it appears that scores on two of the subtests of the CELF are lower than one standard deviation below the average score. The Core Language score is just below one standard deviation from the mean, as well. The child also has an Individualized Education Program (IEP) and may have a language impairment. This participant's possible language impairment may have interfered with implicit learning of the pattern.

In addition, Participant BAA76 did show implicit learning and his language scores reflected the main hypothesis. BAA76's language and cognition scores are, for the most part, within normal limits. Strengths in language may have contributed to this participant's ability to learn the pattern and exhibit implicit learning on the task. These results were what we had anticipated, but they were not consistent across all participants. For example, Participant AAA31 was the other participant who exhibited implicit learning. However, AAA31 scored below one standard deviation on two out of three CELF subtests and both her Core Language Standard Score and Expressive Language Score are below one standard deviation below the mean. These scores indicate there may be a possible language impairment present and therefore, a clear link between language ability and performance on the gesture sequence task cannot be established.

Next, the number of gestural errors produced during the task was analyzed to determine if these errors could be a possible explanation for whether or not implicit learning occurred. Participant BAA81 did not show implicit learning and had low language scores. Consistent with the main hypothesis, this participant also exhibited the highest amount of gesture errors out of all the child participants (see Table 4). Each type of error was exhibited except for no response and the most commonly seen error was amorphous, where the gesture produced was incorrect, not resembling the gesture that was presented on the screen. Due to the number of errors produced, motor difficulties may also have been a reason implicit learning did not occur, making it more difficult to produce the gestures. In addition, the high number of errors caused the child to complete the task at a much slower pace. However, like in the language scores, we did not have consistent findings across participants in this domain. One participant in particular, BAA01, contrasted the results of BAA81 with his performance on the task and gestural errors. This participant did not exhibit implicit learning, but number of errors cannot serve as an explanation for only one gestural error was produced over the course of the entire task.

## Factors for Result Variability and Experiment Improvement

Although language ability and errors in gesture production affected some of the children's performance on the sequential learning task, there were also factors of the task itself that may have caused variability in performance. First of all, it was evident in many of the cases that the children suffered from fatigue while completing the task, which may have strongly affected their times. With that being said, 200 trials may not have been enough opportunities to learn the pattern and reach sequential learning, in addition to slowing down when the pattern was then not present. Since adults exhibited evidence of implicit learning during the task, it may be that that similar evidence would be shown in the children if they had more exposure to the gestures with more trials. However, due to the fatigue of the children, it did not seem possible to increase the length of the task at this time. In addition, in order for the researchers to be able to easily tell when the participants had completed one gesture production, they were asked to place their hand down on the desk after each one. This aspect of the task could have interrupted the sequential learning process. Also, the researcher administering the task had to press the spacebar after each gesture was presented in order to advance to the next gesture. It was observed that often the space bar was pressed at the same time that the participant placed his or her hand on the desk. This factor combined with the sound of the space bar being pressed may have caused a rhythm in gesture production to occur. This may explain a case like BAA77 (see Figure 4) where the speed of the trials levels off, looking very similar from sequential to random sets.

One of the biggest limitations of this study was the small sample size. A larger sample size of children would provide more reliable results and improve the overall experiment. Another limitation lies in the analysis of gesture errors. Only one person examined the children's gestural errors. Having a second, or even third, person assess the children's tapes for errors would also increase reliability. Also, additional coders could help to refine or increase the list of gesture errors. For example, when watching the children complete the task, instances were observed where when presented with a gesture, the child would initially produce an incorrect gesture, but then correct it to the gesture shown on the screen. This was not counted as an error in the current study, but perhaps an ‘adjustment’ error should have been included in the list and counted as an error since it may have affected the sequential learning process. An improvement of this task would be to include additional coders for both reliability checks on gesture error assessment and generation of the error list.

## Future Research

The current task aimed to look at sequential learning and on average, the time it took adults to complete the task indicated sequential learning had occurred. Although sequential learning was not exhibited by all children who participated in the task, it was still present in the data of two children. Possible language impairment and frequent gesture errors seemed to have an effect on times and may have prevented sequential learning from occurring, but there was variability in the results. The pilot data collected in this experiment can be used as a guide in order to alter the task and then administer it on a larger sample of children who do have a diagnosis of SLI, further examining the connections between SLI, sequential learning, and motor skills in gesture production.

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